High Performance Computing
for
Command & Control
Real-Time Decision Support

Real-Time Course of Action Analysis

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Report Documentation Page

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Outline

- **Motivation**

- **Approach**

- **High Performance Computing (HPC) Real-Time Decision Support**

  – **Effects Based Simulation Behaviors**

  – **Automated Scenario Generation**

  – **Modeling Intelligent Adversaries**

  – **Parallel Course of Action (COA) Analysis Framework**

  – **Course of Action Simulation Analysis**

- **Conclusions / Challenges**

- **Dynamic Course of Action (COA)[1] vs enemy COA (eCOA) Analysis done on Paper, if at all**

  – **Manpower Intensive (Blue / Red Teaming)**

  – **Single COA Analysis, need the Ability to Assess Multiple COAs Simultaneously**

- **Automated Wargaming Technology**

  – **Static, don't Represent the Dynamic Behavior (Action / Reaction / Counteraction) of the Adversary or Friendly Force, many Decision Points**

    - **Adversary Actions are Pre-Scripted**

  – **Attrition Based, Force-on-Force – do not Address other Campaign Approaches, such as Effects Based Operations[2]**

- **Neither Approach can be Accomplished in Real-Time**

[1]The sequence of decisions and actions that are accomplished related to a mission. (JP 1-02)

[2]Effects Based Operations are actions taken against enemy systems designed to achieve specific effects that contribute directly to desired military and political outcomes. (AFDD 1)

Approach

- **Challenge**

  - **Simultaneous Real-Time Processing of Situational Data & Operational Plans in Generating Force Structure Simulations for Multiple Predictive Effects Based COA vs. eCOA Analysis**

- **Approach**

  - **Use High Performance Computing (HPC) Simulation Technology for Dynamic Decision Support for Command & Control**

  - **Develop In-house Force Structure Simulation R&D Testbed**

  - **Real-Time Analysis Framework to Provide Realistic Simulated Combat Behaviors to Exercise Developing R&D Applications**
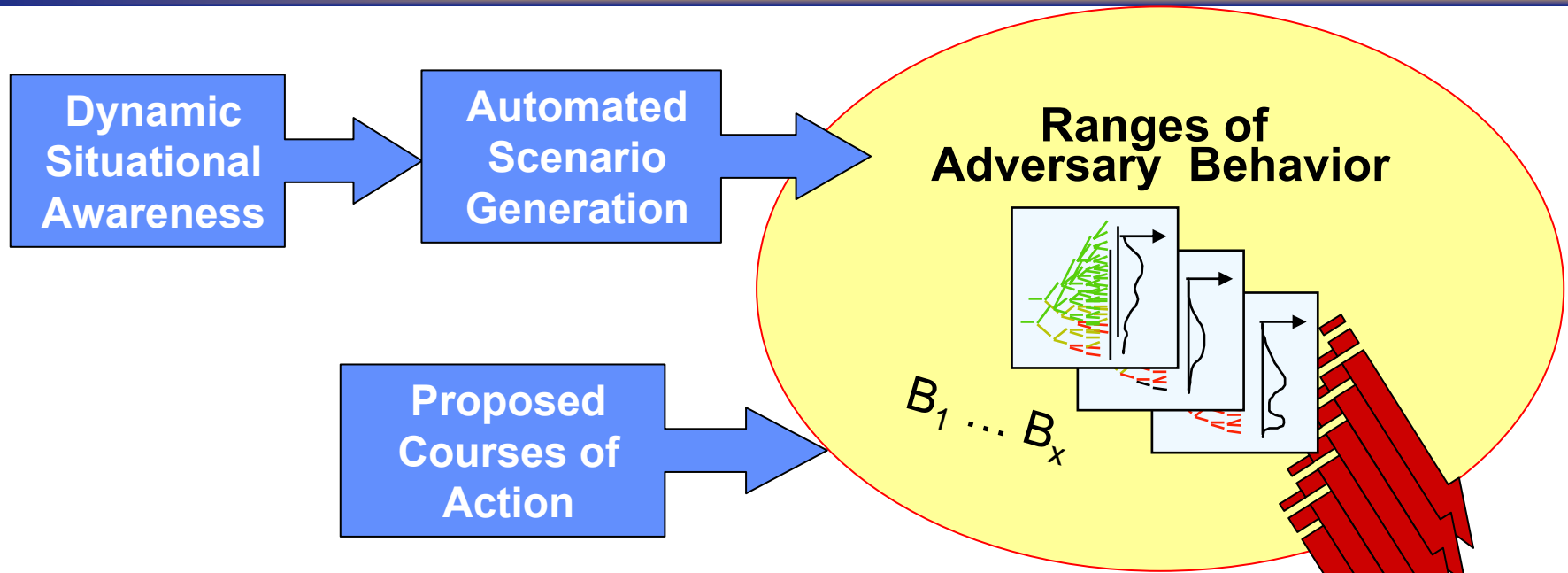
"Static" vs. "Dynamic" Simulation

- **"Static" Simulation: Traditional use of Simulation Technology**
  - Use Wargaming Simulations to Study Scenarios well in Advance
  - Get General Idea of what Might Happen if Similar Scenario Actually Occurs

- **"Dynamic" Simulation: Novel use of Simulation Technology**
  - Use Wargaming Simulations to Assist Decision Makers *While the Scenario is Happening*
  - Quickly Simulate Ahead to Glimpse Possible Futures
  - Evaluate Possible COAs and Multiple Decision Points Within Each COA
  - Dynamic Situational Assessment During Combat Operations, Comparison Against Plans, Alerts on New Threats or Opportunities
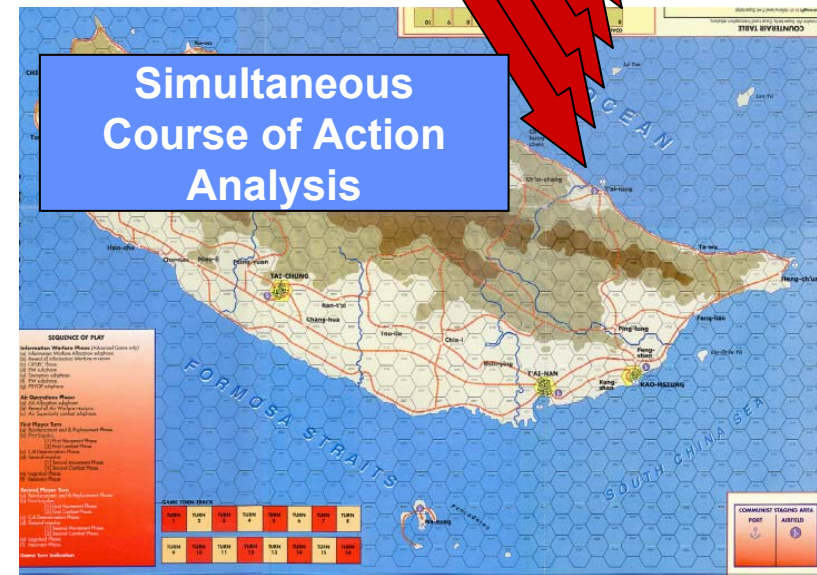
M&S-based COA Analysis
Challenges

Dynamic Situational Awareness → **Automated Scenario Generation** →

Ranges of Adversary Behavior

$$B_1 \dots B_x$$

Proposed Courses of Action →

Simultaneous Course of Action Analysis

Technological Challenges

- **Effects Based / Attrition Based Behaviors**
- **Techniques for Intelligent, Predictive Adversary Behavior**
- **Scenario Generation & Dynamic Update**
- **Scalable Simulation Framework**
- **Real-Time Analysis & Feedback**
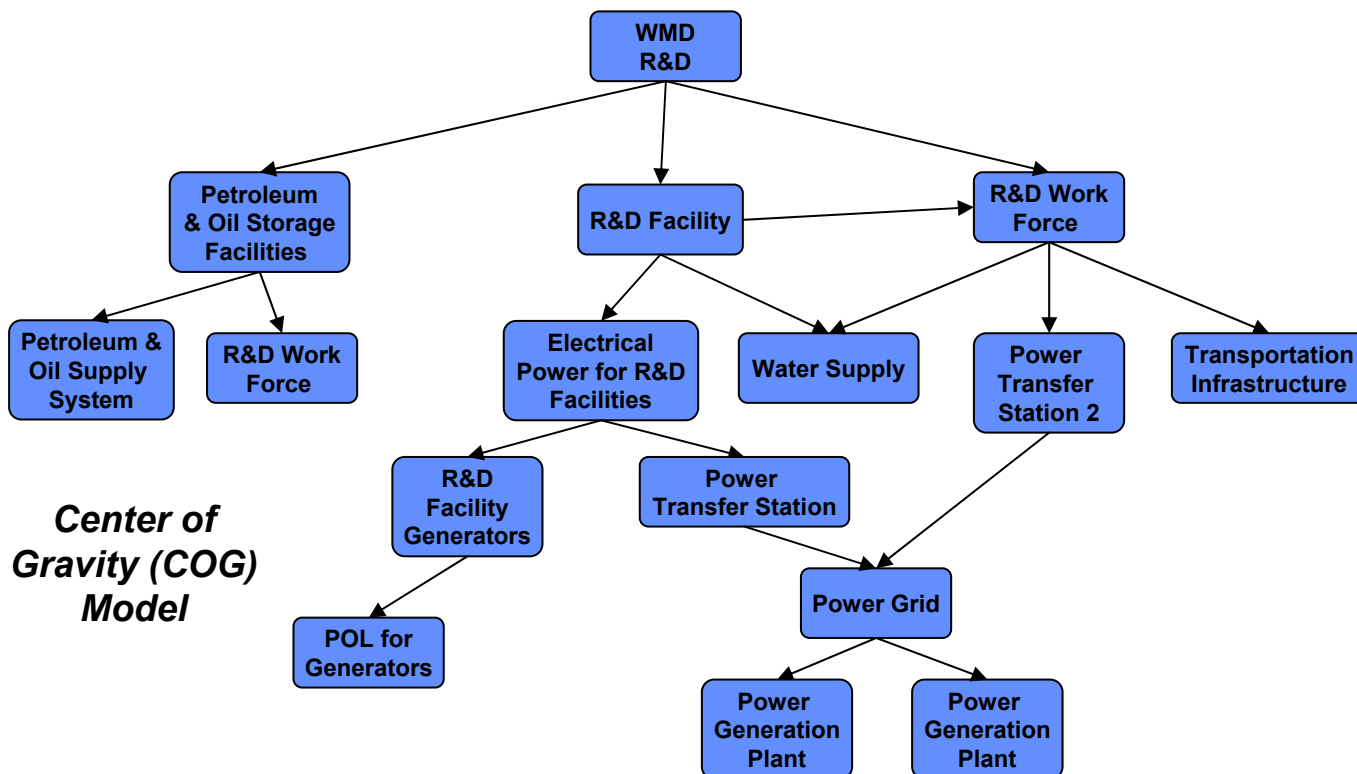- **Dynamic / Interactive HPC Environment**

HPC Real-Time Decision Support

Problem: *Efficient Generation and Analysis of a Range of Course of Action (COA) Alternatives to Anticipate and Shape the Future Battlespace.*

Objective: Use HPC Simulation Technology for Dynamic Decision Support for Command & Control

Challenges:

- Intelligent Adversary Behavior Modeling
- Simulating Effects: Kinetic, Non-Kinetic, Indirect, Complex and Cascading
- Filtering Large COA Evaluation Space
- COA Grading/Evaluation
- Integration of Stored and Real-time Information
- Automating COA Generation Trigger Events

Accomplishments:

- In-House Force Structure Simulation Testbed
- Simultaneous COA/eCOA Evaluation
- Automated Scenario Generation
- Generic EBO Modeling Capability
- EBO Simulation Capability
- COA Analysis/Grading
- Simulation Cloning
- Intelligent Adversary Response

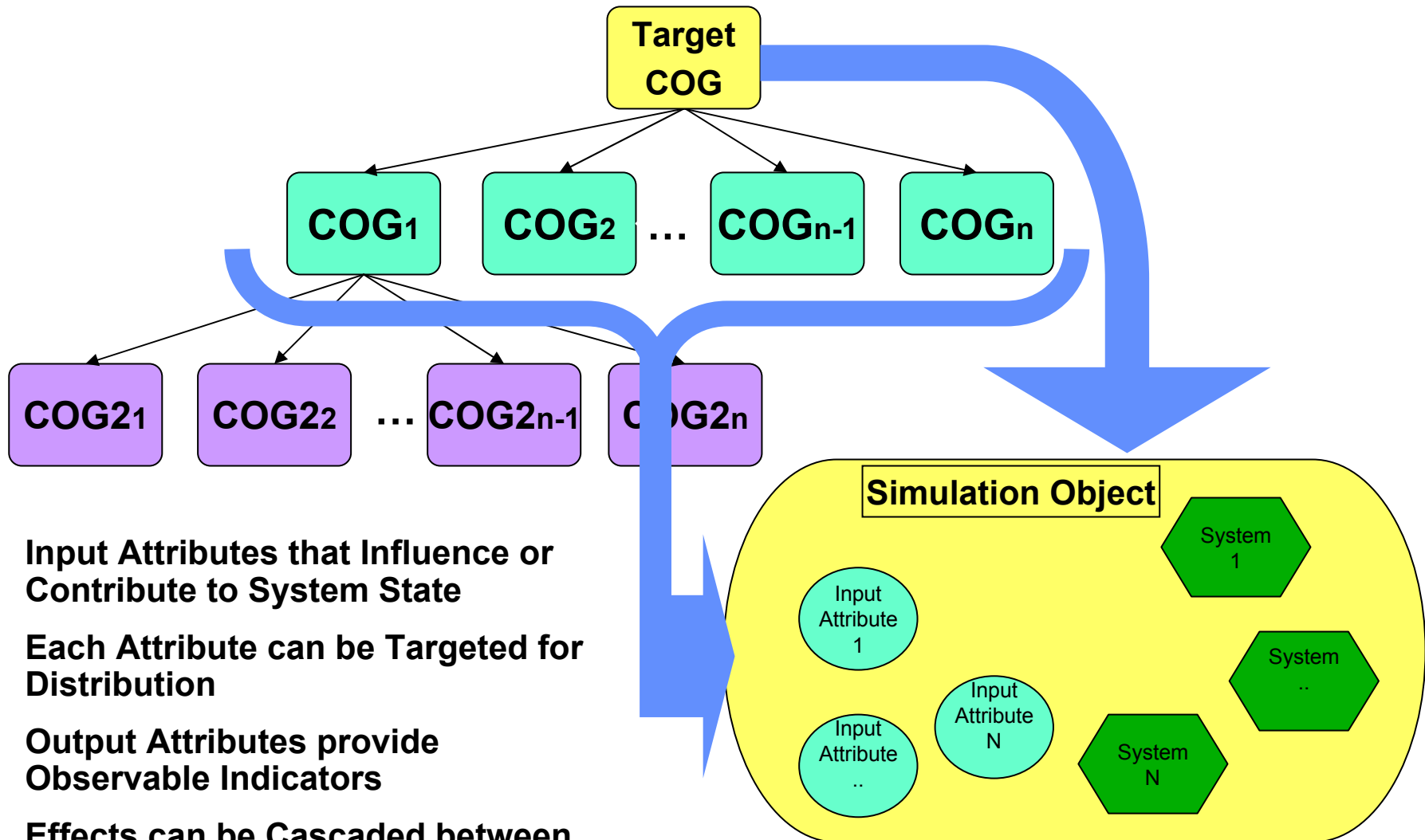# Effects Based Simulation Behaviors

- **Expanding Wargaming Operational Concepts to Integrate EBO Effects for Campaign Assessment**
  - **Complex, Cascading, Recovery**

- **EBO Simulation Objects and Indirect Effects Analysis**

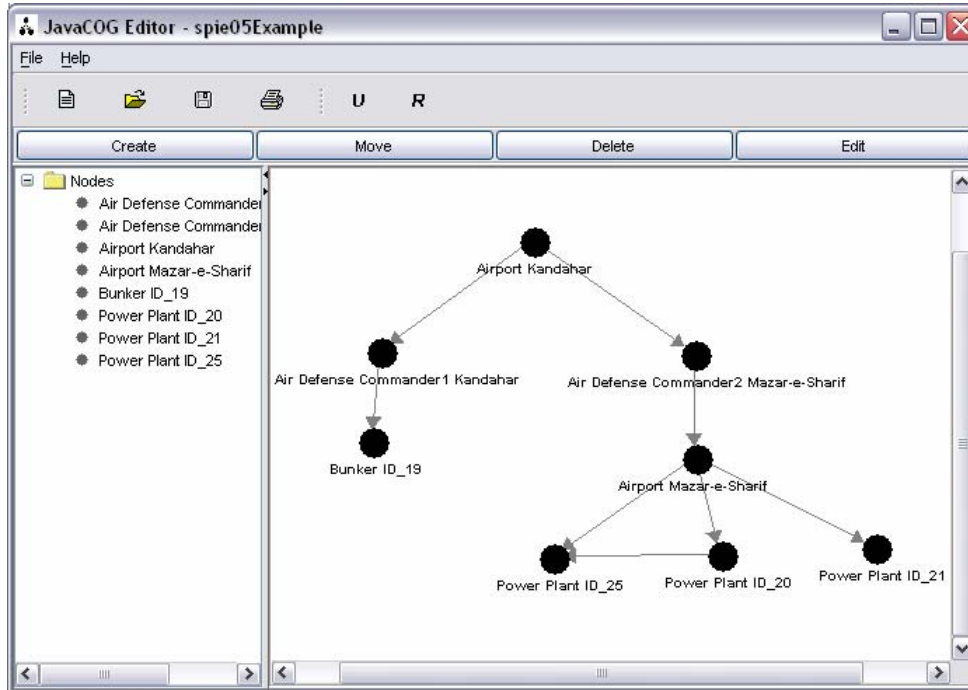- **Generic EBO Simulation Modeling Methodology for Wargaming**

Center of Gravity (COG) Model

```
                              WMD R&D
          ┌─────────────────────┼─────────────────────┐
   Petroleum & Oil         R&D Facility          R&D Work Force
   Storage Facilities
     ┌──────┴──────┐        ┌──────┴──────┐      ┌──────┼──────────┐
  Petroleum &   R&D Work  Electrical    Water   Power        Transportation
  Oil Supply    Force     Power for     Supply  Transfer     Infrastructure
  System                  R&D Facilities        Station 2
                        ┌──────┴──────┐
                      R&D          Power
                      Facility     Transfer
                      Generators   Station
                        │             └──────┐      ┌────┘
                     POL for              Power Grid
                     Generators          ┌────┴────┐
                                     Power       Power
                                     Generation  Generation
                                     Plant       Plant
```

COG Representation in the EBO Object Model

Target COG

COG$_1$ **COG$_2$** ... **COG$_{n-1}$** **COG$_n$**

COG2$_1$ **COG2$_2$** ... **COG2$_{n-1}$** **COG2$_n$**

Simulation Object

System 1

System ..

System N

Input Attribute 1

Input Attribute ..

Input Attribute N

- **Input Attributes that Influence or Contribute to System State**

- **Each Attribute can be Targeted for Distribution**

- **Output Attributes provide Observable Indicators**

- **Effects can be Cascaded between Model Objects**

JavaCOG

Simple, Fictional Example

- **Demonstrates**
  - **Cascading Effects**
  - **Complex Effects**
  - **Recovery Events**
    - **Direct**
    - **Indirect**
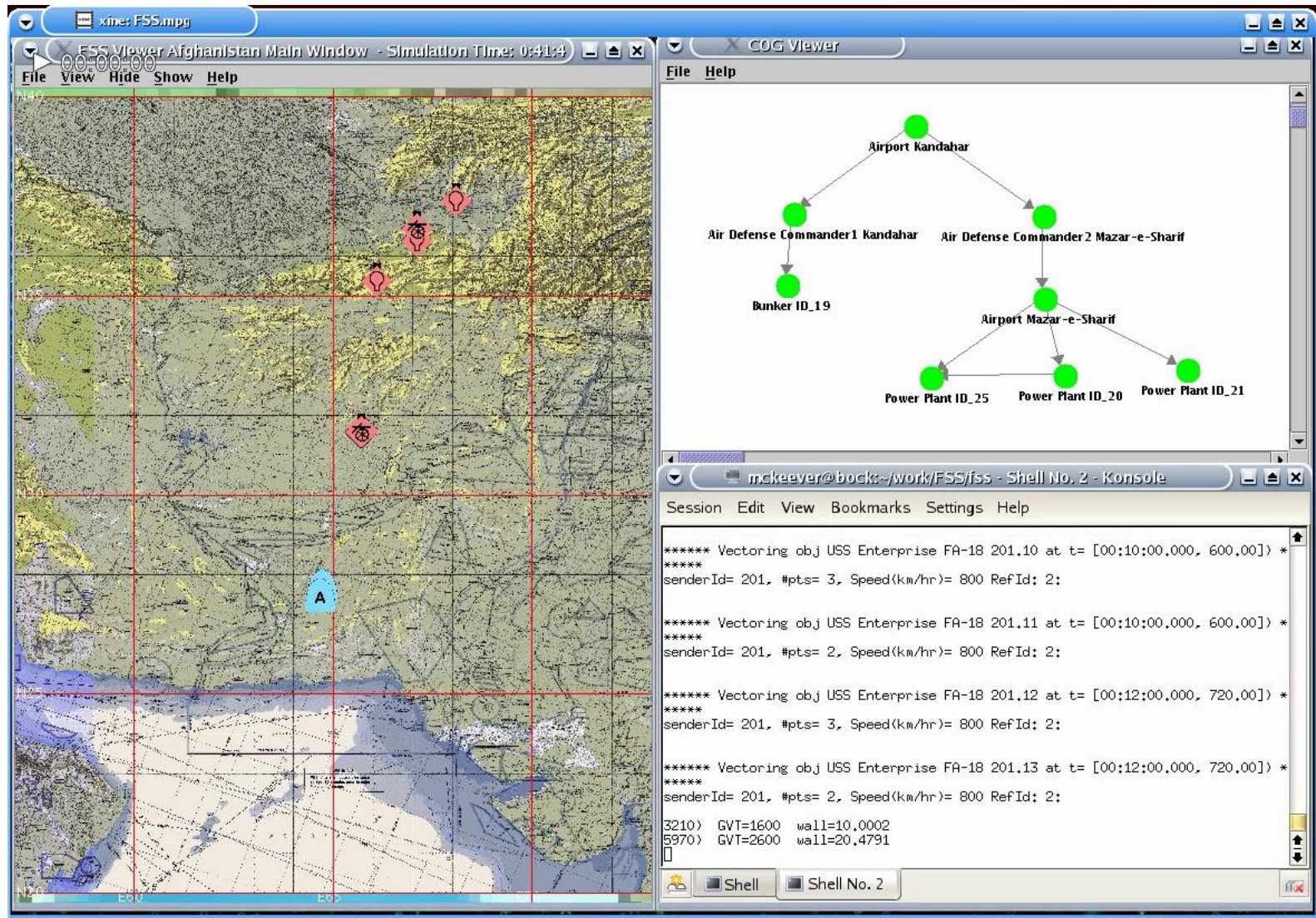- **Compare EBO Results to the Attrition Results**

Simulation Example
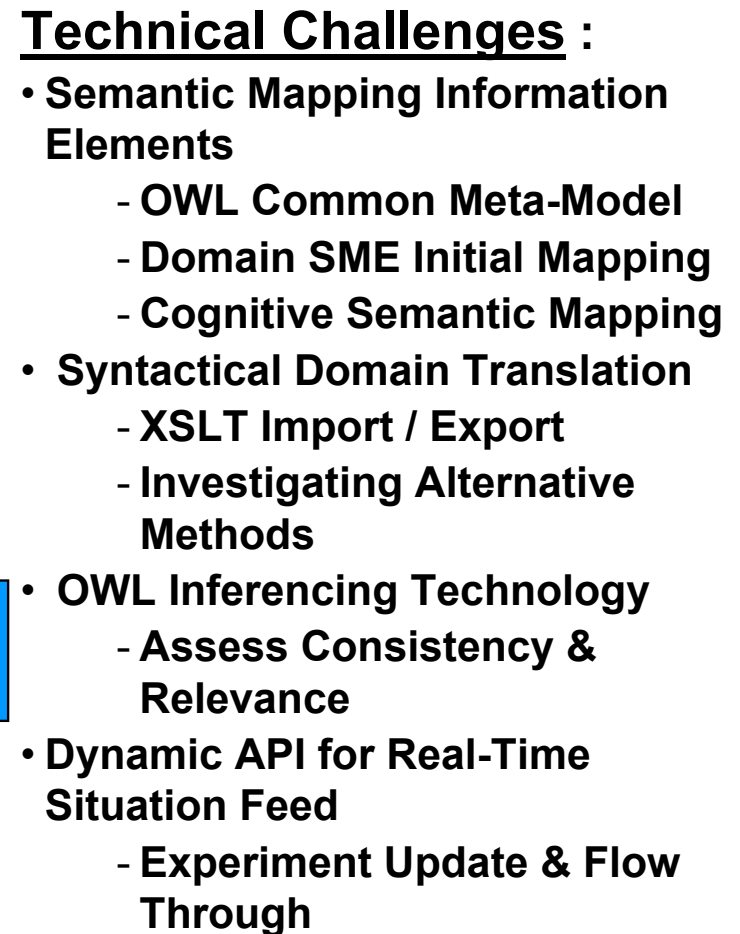
Simple COG Model

Simulation Playback

Simulation Results

TIME (sec)	Symbol	Event Description	With	Without
625	●	Launch Aircraft	⬢	⬢
4625	X	Engage Bunker ID_19; Bunker Destroyed	X	X
4950	⊗	Disable Air Defense Commander 1 **Cascading Event**	⊗	
6400	X	Engage Power Plant ID_25; Power Plant Destroyed	X⊗	X
6400	⊗	Disable Power Plant 20 **Cascading Event**		
7050	X	Engage Power Plant ID_21; Power Plant Destroyed	X	X
7200	⊗	Disable Airbase 2; Air Defense Commander 2; Airbase 1 **Cascading Event**	⊗	
7850	X	Engage Power Plant ID_20; Power Plant Destroyed	X	X
8400	R	Deploy SAM		R
8450	R	Engage Aircraft; Kill 2		R
9150	↑	Recovery of Power Plant ID_25	↑	
9200	↑	Recovery of Airbase 2	↑	
9400	↑	Recovery of Air Defense Commander 2; Airbase 1	↑	
9450	↑	Recovery of Power Plant ID_20	↑	
9600	↑	Recovery of Power Plant ID_21	↑	
11850	↑	Recovery of Bunker ID_19	↑	
12150	↑	Recovery of Air Defense Commander 1	↑	
17500	▲	Land Battle Group; 2 return (with COG four return)	▲	△

Current Scenario Generation

- **Operational-Level Scenario Generation is not Automated**

  - **Process Time in Preparing a Simulated Exercise Measured in Days and Hours Rather than Minutes (or less)**

- **Can't support "what if" analysis to determine best COA**

- **Can't Support Real-Time Scenario Generation**

  - **Predictive Battlespace Awareness Requires the Ability to Automatically Generate Scenarios to Support Look Ahead**

- **Must Include an Effects Based Focus**

Automated Scenario Generation

Simultaneous Data Feeds, both Stored and Real-Time, used to Generate Multiple Blue COAs

Inputs
- TBMCS
- MIDB
- Legacy data
- Strategy Tools

SGen Toolset
- Integration Agent
- SGen Meta Model/Data
- Translation
- Translation
- SGen Meta Data Mapping Editor
- EBOWS - Storm
- EADSim
- FSS
  - EBO – Effects
  - Attrition Analysis

Technical Challenges :
- Semantic Mapping Information Elements
  - OWL Common Meta-Model
  - Domain SME Initial Mapping
  - Cognitive Semantic Mapping
- Syntactical Domain Translation
  - XSLT Import / Export
  - Investigating Alternative Methods
- OWL Inferencing Technology
  - Assess Consistency & Relevance
- Dynamic API for Real-Time Situation Feed
  - Experiment Update & Flow Through

SGen

1. Current Mission and COAs that comprise its execution.

4. As orders for the squadron are created, they are added to the Tabbed Pane for COG-based target assignment.

2. Selecting a COA highlights the list of squadrons available to execute the COA. As squadrons are selected, their properties are displayed.

5. Aircraft from the squadron can be assigned or unassigned to the target.

3. Creating a task order for the Mission-COA-Squadron adds it to the overall mission timeline (Gantt Chart) and creates an order to begin COG-based target assignment

4. The targets may be filtered based on the COG(s) they impact, and assigned to the current order.

3.1. Overall timeline for each order in the mission.

Order information can be used to construct simulations for execution at the unit, squadron, COA and mission levels.

4.1 As targets are assigned to the order, timeline shows the time-on-target within the order.
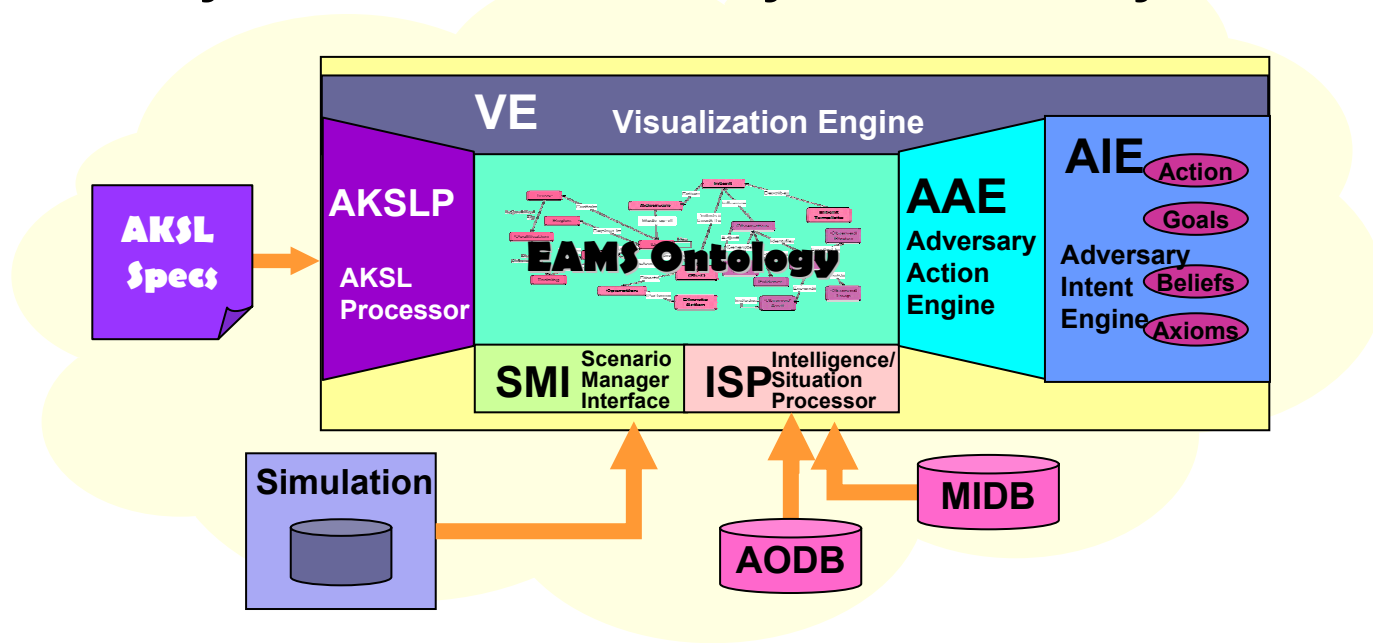
Modeling Intelligent Adversary Behaviors

- **Current Generation Wargaming Technologies Execute a Pre-Scripted Sequence of Events for an Adversary – Don't Survive beyond the first Campaign Action**

- **Provide a Dynamic Simulation Capability that Incorporates Potential Adversary Actions**

  - **Adversary COAs don't need to be predetermined**

- **Incorporate Sequential Action / Reaction Analysis Concept into Future Simulations**

- **More Robust COA Assessment**

  - **Multiple What-if Analysis**

- **Predictive Battlespace Awareness (PBA)**

Emergent Adversarial Modeling System (EAMS)

- **Inferencing System Framework Based on Bayesian Belief Networks**

- **Inferencing System Captures Adversary Behavior Attributes**
  - **Beliefs, Perceptions, Biases, Desired End-states**

- **Adversary Modeling System Inputs Observables from the Simulation System and Infers, in order of Likelihood, the Adversary Goals and Intents**

- **Adversary Behavior and Actions are Calculated and input to the Simulation System and Executed by the Adversary Force**
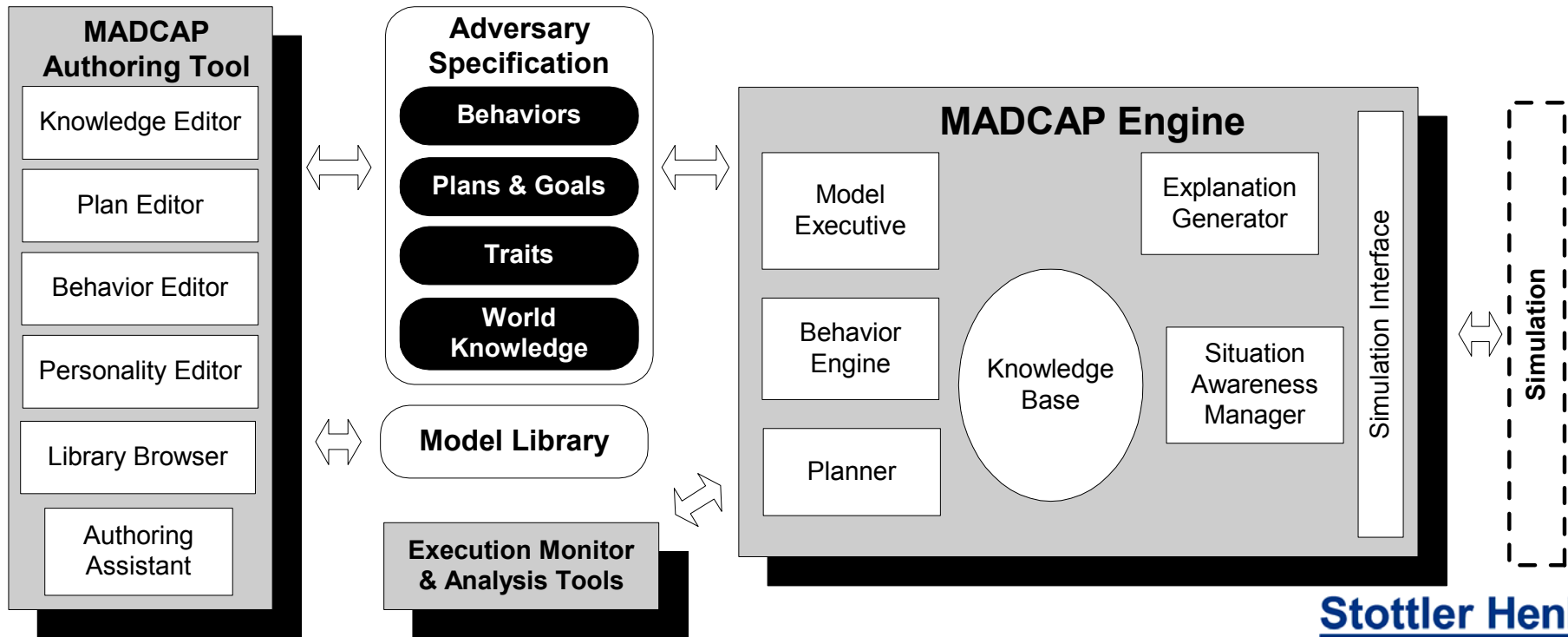
Authorable Adversary Modeling for COA Assessment

- **Utilizes Hierarchical Planning and Ruled-Based Techniques**

- **Adversary Models Based on Objectives, Actions, Predicates and Behaviors, including aspects of cultural and extra-cognitive factors**

- **Attributes Captured by a Model Execution Engine**

- **Execution Engine Dynamically Determines Adversary Actions based on the Adversary Model and the Current State of the Simulated World**

MADCAP Authoring Tool
- Knowledge Editor
- Plan Editor
- Behavior Editor
- Personality Editor
- Library Browser
- Authoring Assistant

Adversary Specification
- Behaviors
- Plans & Goals
- Traits
- World Knowledge

Model Library

Execution Monitor & Analysis Tools

MADCAP Engine
- Model Executive
- Behavior Engine
- Planner
- Knowledge Base
- Explanation Generator
- Situation Awareness Manager
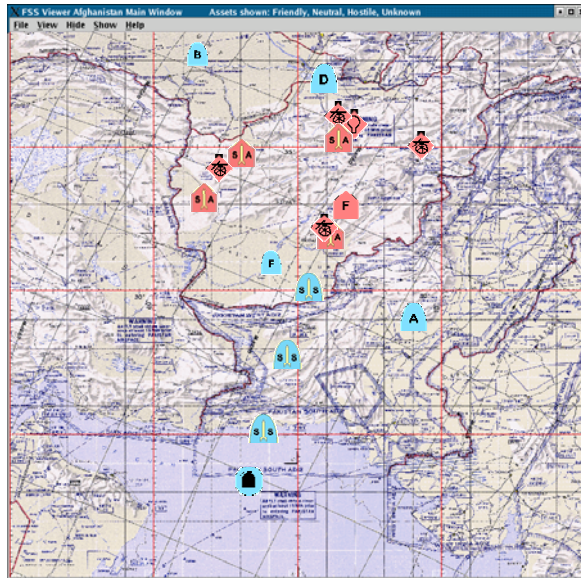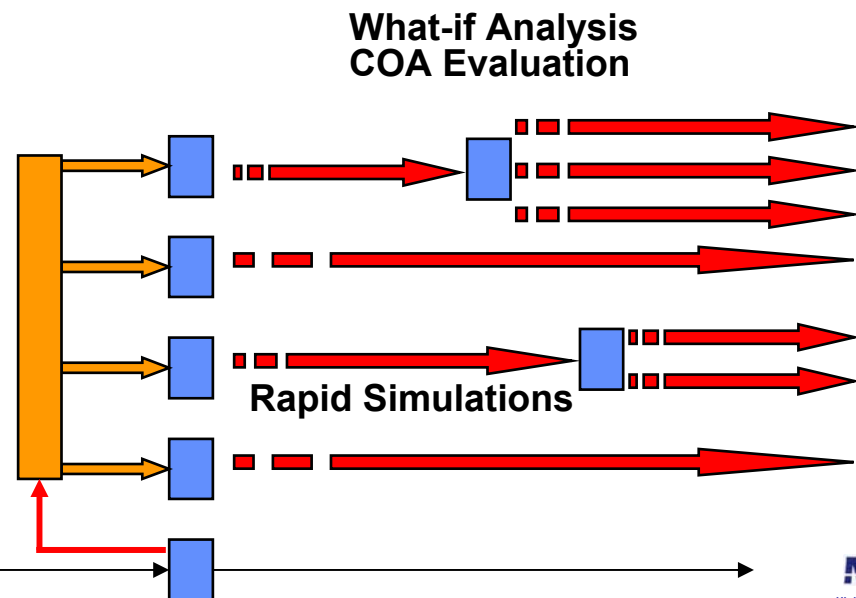- Simulation Interface

Simulation

HPC COA Analysis Framework

- **Simulation Framework for Faster than Real-Time Parallel COA Evaluations**

- **Utilize Parallel Event Simulation to Harness Computing Power of Many CPUs**

- **Continuously Emulate Common Operating Picture with Real-Time ISR Inputs**

- **Processing Mechanism to Clone Emulation State and Evaluate Alternative COAs Simultaneously or Predict Future Battlespace**

What-if Analysis COA Evaluation

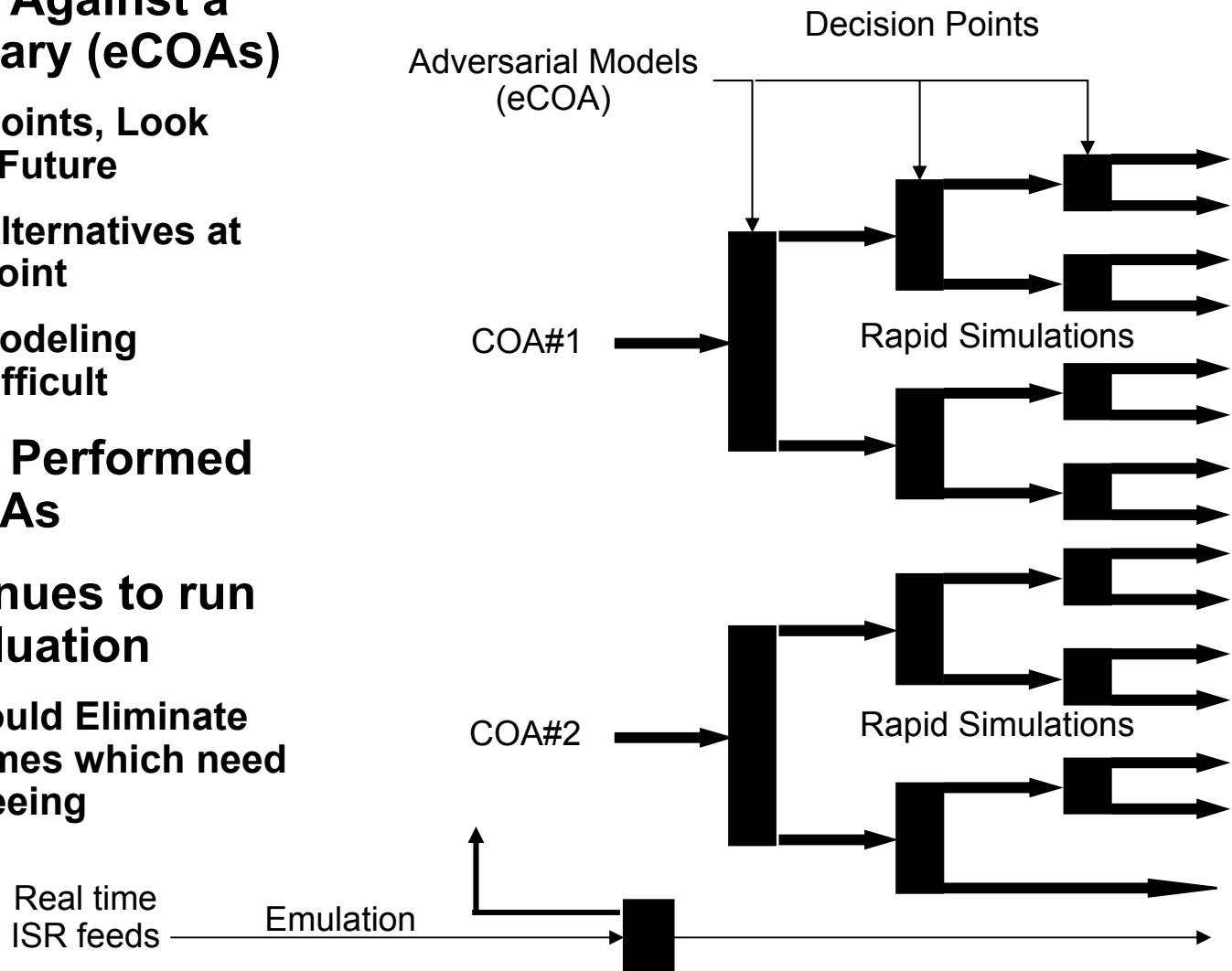**Rapid Simulations**

Emulation (Basis Simulation)

Simulation Cloning Example

- **Can Evaluate More Friendly COAs in Parallel Against a Dynamic Adversary (eCOAs)**

  - **More Decision Points, Look Further into the Future**

  - **Evaluate More Alternatives at each Decision Point**
    - **Adversary Modeling Extremely Difficult**

- **What-if Analysis Performed on Unlimited COAs**

- **Emulation Continues to run during COA Evaluation**

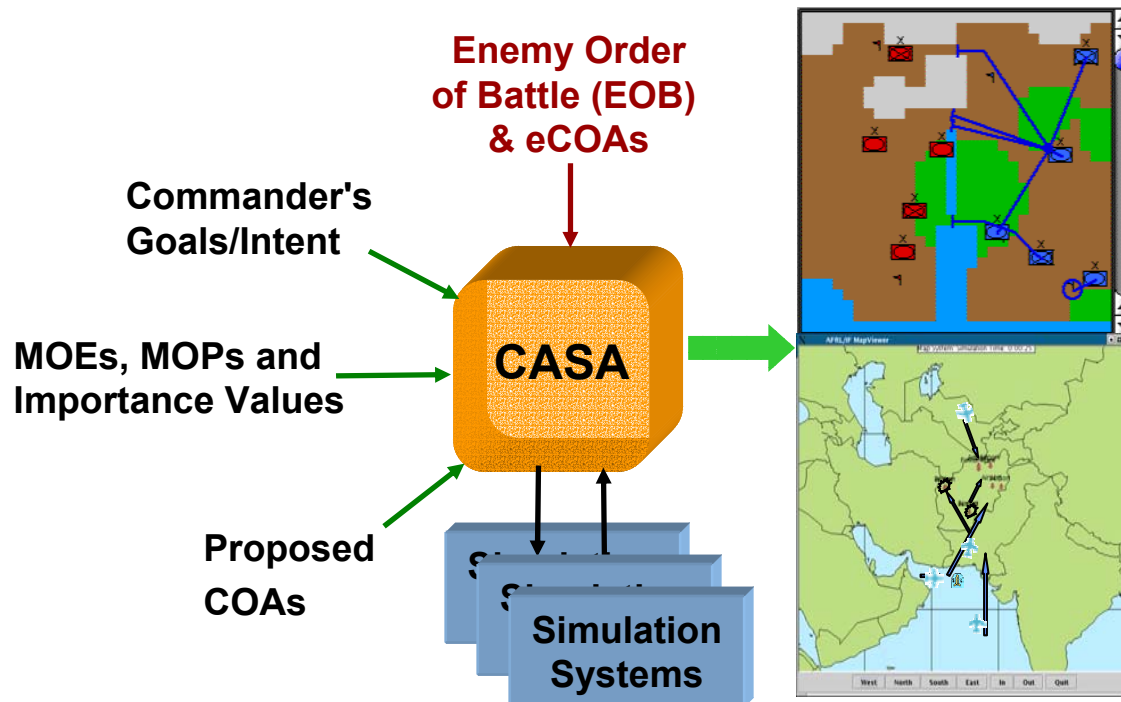 - **New ISR Data could Eliminate Potential Outcomes which need to be Pruned Freeing Resources**

Decision Points

Adversarial Models (eCOA)

COA#1

Rapid Simulations

COA#2

Rapid Simulations

Real time ISR feeds

Emulation

Course of Action Simulation Analysis (CASA)

- **Define appropriate Measures of Effectiveness/ Measures of Performance (MOEs/MOPs) for COAs**

- **Identify a Very Low Level, Fundamental and Common set of Characteristics that, when Aggregated, can be used to Describe any MOP or MOE**

- **Provide a Means of Comparison for Disparate Approaches of Multiple COAs**

- **Metrics to Rate and Rank the Relative Merit of Evaluated COAs**

- **Develop Data Visualization Techniques**

Enemy Order of Battle (EOB) & eCOAs

Commander's Goals/Intent

MOEs, MOPs and Importance Values

CASA

Proposed COAs

Simulation Systems

COA 1: Aggregate Score 92.3
  + MOE 1-1: 78.2 ; Weighting: 3.0
  + MOE 1-2: 64.2 ; Weighting: 2.7
     - MOP 1: 83.4 ; Weighting: 1.7
       - Raw Data
          - Attrition: 4.7 %
          - Successful Missions: 87 %
          - Targets Destroyed: 419
             …
  + MOE 1-3: 64.2 ; Weighting: 0.3

COA 2: Aggregate Score 87.6
  + MOE 2-1: 84.2 ; Weighting: 0.9
  + MOE 2-2: 52.3 ; Weighting: 1.2
  + MOE 2-3: 98.7 ; Weighting: 1.8
…

High Performance Computing Real-Time Decision Support

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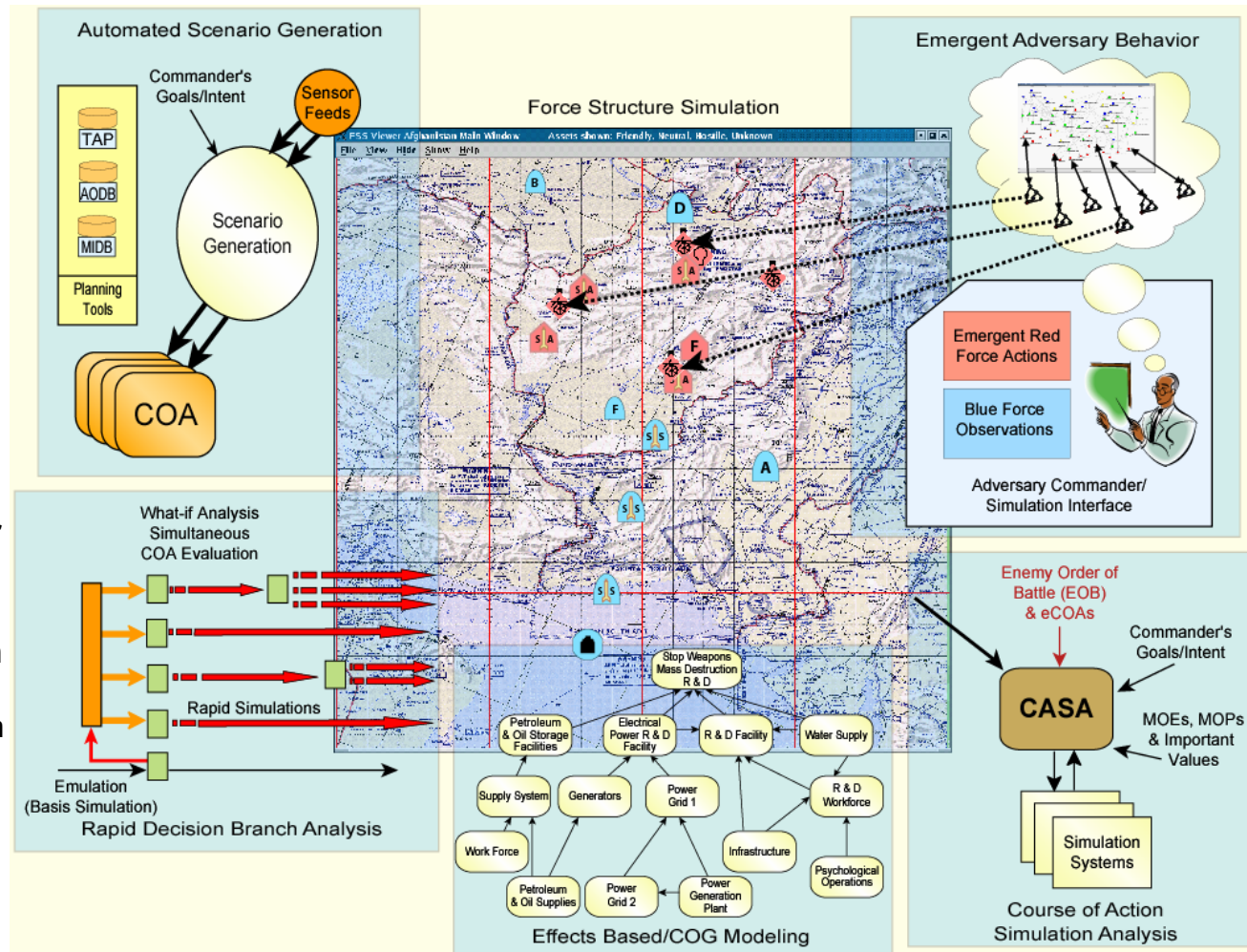
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- **Simulating Effects: Kinetic, Non-Kinetic, Indirect, Complex and Cascading**
- **Filtering Large COA Evaluation Space**
- **COA Grading/Evaluation**
- **Integration of Stored and Real-time Information**
- **Automating COA Generation Trigger Events**

Accomplishments:

- **In-House Force Structure Simulation Testbed**
- **Simultaneous COA/eCOA Evaluation**
- **Automated Scenario Generation**
- **Generic EBO Modeling Capability**
- **EBO Simulation Capability**
- **COA Analysis/Grading**
- **Simulation Cloning**
- **Intelligent Adversary Response**

Some Challenges

- **New Models of Computation for Human Behavior Modeling**
  - **Dynamic Model Generation**
  - **Ability to Reason About All Adversary Intentions**
- **Data Analysis**
  - **Mergence of Stored and Real-Time Information – Continuous Projection into the Future**
  - **Continuously Assess Engagement Results vs. Predictions**
  - **Automated COA Generation, Trigger Events**
  - **Modeling Data Uncertainty, Conflict**
  - **Common Operating Picture**
- **Continuous Situation Awareness / Decision Support Loop**
- **System of System Analysis**
- **COA Robustness**

References

- **Surman, Hillman, Santos, *Adversarial Inferencing for Generating Dynamic Adversary Behavior*, Enabling Technology for Simulation Science VII Conference, Orlando FL, April 2003**

- **Krause, Lehman, Koziarz, *Automated Scenario Generation*, Enabling Technology for Simulation Science VII Conference, Orlando FL, April 2003**

- **McKeever, Gilmour, Hillman, *An Approach to Effects Based Modeling for Wargaming*, Enabling Technology for Simulation Science VIII Conference, Orlando FL, April 2004**

- **Gilmour, Hanna, Blank, *Dynamic Resource Allocation in an HPC Environment*, DOD HPC Modernization Program 2004 Users Group Conference, Williamsburg VA, June 2004**

- **Gilmour, Hanna, Koziarz, McKeever, Walter, *High-Performance Computing for Command and Control Real-Time Decision Support*, AFRL Tech Horizons, February 2005, http://www.afrlhorizons.com**